MULTI-TRACK SPEECH SYNTHESIZER

FIELD OF THE INVENTION

The present invention relates generally to a multi-track speech synthesizer, and more particularly, to a multi-track speech synthesizer utilizing current switch and push-pull output technique.

BACKGROUND OF THE INVENTION

For consumer electronic products, digital sound effect is an important function. Fig. 1 shows the functional block diagram of a traditional multi-track speech synthesizer utilizing digital to analog converter (DAC). A DAC speech synthesizer 100 comprises three basic units, volume control unit 101, signal transform unit 102 and drive unit 103, and a plurality of signal transform units 102 can be connected directly to form a multi-track speech synthesizer.

Two volume control units 101 accept control signals V_{ctrl1} and V_{ctrl2} respectively and produce control biases V_{bias1} and V_{bias2}. Two signal transform units 102 accept control biases V_{bias1} and V_{bias2} and

pulse code modulation (PCM) signals PCM_1 and PCM_2 respectively and transform them to analog speech signal I_{vo1} and I_{vo2}. The drive unit 103 receives the current from the directly coupled analog speech signals I_{vo1} and I_{vo2} and amplifies the coupled current I_{vo} to drive the speaker 104. Fig. 2A is the waveform of a 7-bits sinusoidal PCM signal, and Fig. 2B is the waveform of the analog speech signal I_{vo} after the PCM signal shown in Fig. 2A is processed by the signal transform unit 102 shown is Fig. 1. Assuming that the zero point of each analog speech signal I_{vo} is 1.5 mA, the direct current component increases due to the accumulation resulted from the directly coupled signals, which increases the power consumption. For applications of portable electronic products whose power supply is battery, such large power consumption should be avoided. Moreover, to prevent the transistor 105 within the drive unit 103 from saturated to result in a speech distortion, a bypass resistor 106 is inserted thereof, which further results in the speech distortion more seriously.

SUMMARY OF THE INVENTION

To resolve the above problems, the present invention is therefore directed to a multi-track speech synthesizer with drive current having no direct current component to reduce power consumption.

According to the present invention, a multi-track speech synthesizer comprises a plurality of signal transform units, a plurality of current switch units, a comparison unit and a current output unit. The signal transform units accept and transform a series of digital speech codes to be an analog speech signal with its negative half-cycles inverted respectively. Each current switch unit is connected to a signal transform unit respectively, and receives the analog speech signal from the signal transform unit. Each current switch unit has a first output terminal and a second output terminal to have the current of the positive half-cycle of the analog speech signal flowing out from the first output terminal and flowing in from the second output terminal and the current of the negative half-cycle of the analog speech signal flowing out from the second output terminal and flowing in from the first output terminal. The first output terminals of each current switch unit are connected to each other and forms a first connected output terminal. The second output terminals of each current switch unit are connected to each other and forms a second connected output terminal. The voltages from the first and second connected output terminals are compared by the comparison unit so as to send out a control signal. The current output unit accepts the currents from the first and second connected output terminals and sends out the currents from a first drive terminal or a second drive terminal depending on the control signal from the comparison unit.

The multi-track speech synthesizer according to the present invention uses the current switch technique to process the positive and negative half-cycles of each speech signal separately such that the currents have their zero point to be 0 and are directly coupled, the comparison unit to compare the voltages of the directly coupled signals to send out the control signal to control the current output unit, and the current output unit to send out the drive current by push-pull output technique to drive a speaker. Since the drive current has no direct current component, the power consumption is reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference may be had to the following description of exemplary embodiments thereof, considered in conjunction with the accompanying drawings, in which:

Fig. 1 shows the functional block diagram of a traditional DAC speech synthesizer;

Fig. 2(A) is the waveform of a 7-bits sinusoidal PCM signal;

Fig. 2(B) is the waveform of the analog speech signal after the PCM signal shown in Fig. 2(A) is processed by the signal transform unit 102 shown is Fig. 1;

Fig. 3 is the functional block diagram of a multi-track speech synthesizer according to the present invention;

Fig. 4 is a circuit diagram for the signal transform unit shown in Fig. 3;

Fig. 5 shows the waveforms of the output and input of the signal transform unit shown in Fig. 4, in which Fig. 5(A) is the waveform of a PCM signal and Fig. 5(B) is the waveform of the output current;

Fig. 6 is a control diagram for the current switch unit shown in Fig. 3;

Fig. 7 shows the related waveforms of the current switch unit shown in Fig. 6, in which Fig. 7(A) are the output waveforms of each current source and Fig. 7(B) is the output waveform from the output terminal;

Fig. 8 is a control diagram for the current output unit shown in Fig. 3;

Fig. 9 shows the switch circuit diagrams applied to the present invention, in which Fig. 9(A) is the current output type switch and Fig. 9(B) is the current input type switch;

Fig. 10 is a circuit diagram for the current switch unit shown in Fig. 3; and

Fig. 11 is a circuit diagram for the current output unit shown in Fig. 3.

DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 3 is the functional block diagram of a multi-track speech synthesizer according to the present invention. A speech synthesizer 30 comprises a plurality of volume control units 31, a plurality of signal transform units 32, a plurality of current switch units 33, a comparison unit 34 and a current output unit 35.

The volume control unit 31 receives a control signal V_{ctrl} and produces a control bias V_{bias}, whose function is same as the volume control unit 101 of the traditional DAC speech synthesizer shown in Fig. 1. The control bias V_{bias} is sent to the signal transform unit 32 for volume control. Each signal transform unit 32 receives a series

of digital speech signals (PCM_1, PCM_2, ...) respectively and transforms them to be positive valued analog speech currents I_{vo1}, I_{vo2}, ... for output, and sends out the most significant bit (MSB) signal and the inverted signal of the digital speech signal, for example, D16 and D16B, D26 and D26B, ... of 7-bits digital speech signals PCM_1, PCM_2, ... respectively. The current switch unit 33 is used to accept the analog speech currents I_{vo1}, I_{vo2}, ... and the MSB signals D16 and D16B, D26 and D26B, ..., and convert the analog speech currents I_{vo1}, I_{vo2}, ...to be analog speech currents I_{va1} and I_{vb1}, I_{va2} and I_{vb2}, ... that vary in-between positive and negative value and have a zero point of 0 and are sent out from first and second output terminals O_{va} and O_{vb}. As shown in Fig. 3, the first output terminals O_{va} of each current switch unit 33 are connected together to form a first connected output terminal O_a, and the second output terminals O_{vb} of each current switch unit are also connected together to form a second connected output terminal O_b. The comparison unit 34 produces control signals S_1 and S_2 depending on the voltages of the first and second connected output terminals. The current output unit 35 accepts the currents from the first and second connected output terminals and produces a drive current under control of the control signals S_1 and S_2 and sent to a speaker 36 from first drive terminals V_{o1} and V_{o2}.

Fig. 4 shows a circuit diagram for the signal transform unit 32 of the speech synthesizer according to the present invention. The

signal transform unit 32 receives the control bias V_{bias} and a series of PCM digital speech signal such as 7-bits signal D[6:0], and then converts the speech signal to a positive valued analog speech signal I_{vo}. The signal transform unit 32 includes a switched buffer 321 and a switched inverter buffer 322 connected in parallel, and an DAC 323. Both the switched buffer 321 and switched inverter buffer 322 receive the lower bits data D[5:0] of the PCM digital speech signal and are controlled by the MSB signal (D6), that is when MSB=1, the switched buffer 321 is enabled and the lower bits data D[5:0] is sent to the DAC 323; in the opposite situation, when MSB=0, the switched inverter buffer 322 is enabled and the lower bits data D[5:0] is inverted and sent to the DAC 323. The DAC 323 converts the lower bits data D[5:0] and its inverse DB[5:0] that sent by the switched buffer 321 and by the switched inverter buffer 322 to be the analog speech signal I_{vo}. As shown in Fig. 5(A), the zero point of a sinusoid PCM speech signal is 40H, so the most significant bit MSB of the front half-cycle is 1 and the most significant bit of the rear half-cycle is 0. Therefore the signal transform unit 32 converts the PCM digital speech signal and produces the analog speech signal I_{vo} as shown in Fig. 5(B).

A control diagram for the current switch unit 33 is shown in Fig. 6. The current switch unit 33 includes four switched current sources 331, 332, 333 and 334, among which the current sources 331 and 332 are connected in serial and their connected node is the

first output terminal O_{va}, and the current sources 333 and 334 are connected in serial and their connected node is the second output terminal O_{vb}. The control model of the current switch unit 33 can be separated into two states, positive half-cycle state (D6=1 and D6B=0) and negative half-cycle state (D6=0 and D6B=1). When in the positive half-cycle state, the first and fourth switched current sources 331 and 334 are active, then a current I_{va} in proportion to the analog speech signal I_{vo} flows out from the first output terminal O_{va} and a current I_{vb} equal to the current I_{va} flows in from the second output terminal O_{vb}. On the contrary, when in the negative half-cycle state, the second and third switched current sources 332 and 333 are active, then a current I_{vb} in proportion to the analog speech signal I_{vo} flows out from the second output terminal O_{vb} and a current I_{va} equal to the current I_{vb} flows in from the first output terminal O_{va}. The current waveforms of the switched current sources 331, 332, 333 and 334 are shown in Fig. 7(A), and the current waveforms of the first and second output terminals O_{va} and O_{vb} are shown in Fig. 7(B).

In reference to Fig. 3, the comparison unit 34 is used to compare voltages of the first and second connected output terminals O_a and O_b so as to send out control signals S_1 and S_2. The relationships between the voltages and currents of the first and second connected output terminals and the control signals S_1 and S_2 are listed in Table 1 under the assumption that two current switch

units 33 are connected to each other, in which $I_{na} = I_{va1} + I_{va2}$.

Table 1

Input conditions	Output currents (voltages)	Control signals
$I_{va1}>0$, $I_{va2}>0$	$I_{na}>0$ ($V_{na}>V_{nb}$)	$S_1=1$, $S_2=0$
$I_{va1}<0$, $I_{va2}<0$	$I_{na}<0$ ($V_{na}<V_{nb}$)	$S_1=0$, $S_2=1$
$I_{va1}>0$, $I_{va2}<0$	(a) $I_{na}>0$ ($V_{na}>V_{nb}$)	(a) $S_1=1$, $S_2=0$
	(b) $I_{na}<0$ ($V_{na}<V_{nb}$)	(b) $S_1=0$, $S_2=1$
$I_{va1}<0$, $I_{va2}>0$	(a) $I_{na}>0$ ($V_{na}>V_{nb}$)	(a) $S_1=1$, $S_2=0$
	(b) $I_{na}<0$ ($V_{na}<V_{nb}$)	(b) $S_1=0$, $S_2=1$

A control diagram for the current output unit 35 is shown in Fig. 8. The current output unit 35 includes control switches 351 and 352, and switched current sources 353 and 354, all of them are controlled by control signals S_1 and S_2. The current output unit 35 sends out a drive current to the speaker 36 from the first and second drive terminals V_{o1} and V_{o2}. The current output unit 35 sends out the current in two modes, that is, when $S_1=1$ and $S_2=0$, the control switch 351 and switched current source 353 are conducted for the drive current to flow out from the first drive terminal V_{o1} and flow in from the second drive terminal V_{o2} through the speaker 36, and when $S_1=0$ and $S_2=1$, the control switch 352 and switched current source 354 are conducted for the drive current to flow out from the second drive terminal V_{o2} and flow in from the first drive terminal V_{o1} through the speaker 36. Thereby the current output unit 35 drives

the speaker 36 with a push-pull type current output.

Fig. 9 shows the switch circuit diagrams applied to the present invention, in which Fig. 9(A) is the current output type switch and Fig. 9(B) is the current input type switch. As shown in Fig. 9(A), when the voltage of the first input terminal I_1 of the switch SW_1 is low and the voltage of the second input terminal I_2 of the switch SW_1 is high, the switch SW_1 is conductive and makes the third input terminal I_3 conducted to the output terminal O_1, otherwise the switch SW_1 is not conducted. In Fig. 9(B), when the voltage of the first input terminal I_1 of the switch SW2 is low and the voltage of the second input terminal I_2 of the switch SW_2 is high, the switch SW_2 is conductive and makes the third input terminal I_3 conducted to the output terminal O_1, otherwise the switch SW_2 is not conducted.

A circuit diagram for the current switch unit 33 is shown in Fig. 10. The first switched current source 331 of the current switch unit 33 is controlled by SW_1 switch 3313, and a current mirror composed of transistors 3311 and 3312 is used to control the value of its output current. A current mirror composed of transistors 335 and 3321 receives the current I_{vo} and its output is used for the input of the current mirror composed of transistors 3311 and 3312, thereby the switched current source 331 can send out a current that is proportional to the current I_{vo}. The first input I_1 of the switch

3313 is connected with D6B and the second input I_2 is connected with D6. The second switched current source 332 of the current switch unit 33 is controlled by SW_2 switch 3323, and a current mirror composed of transistors 335 and 3322 is used to control the value of its output current. The input of this current mirror is I_{vo}, thus the switched current source 332 can send out a current that is proportional to the current I_{vo}. The first input I_1 of the switch 3323 is connected with D6 and the second input I_2 is connected with D6B. The third switched current source 333 of the current switch unit 33 is controlled by SW_1 switch 3333, and a current mirror composed of transistors 3311 and 3331 is used to control the value of its output current. The input of this current mirror is the output of the current mirror composed of transistors 335 and 3321, thus the switched current source 333 can sent out a current that is proportional to the current I_{vo}. The first input I_1 of the switch 333 is connected with D6 and the second input I_2 is connected with D6B. The fourth switched current source 334 of the current switch unit 33 is controlled by SW_2 switch 3343, and a current mirror composed of transistors 335 and 3341 is used to control the value of its output current. The input of this current mirror is I_{vo}, thus the switched current source 332 can send out a current that is proportional to the current I_{vo}. The first input I_1 of the switch 3343 is connected with D6 and the second input I_2 is connected with D6B. When I_{vo} is in the positive half-cycle, the voltage of D6 is high and that of D6B is low, the switches 3313 and 3343 are therefore conductive, and the

current flows out from the first output terminal O_{va} and flows in from the second output terminal O_{vb}. In contrast, when I_{vo} is in the negative half-cycle, the voltage of D6 is low and that of D6B is high, the switches 3323 and 3333 are therefore conductive, and the current flows out from the first output terminal O_{vb} and flows in from the second output terminal O_{va}.

A circuit diagram for the current output unit 35 is shown in Fig. 11. The first control switch 351 and the second control switch 352 of the current output unit 35 are transistors with one terminal thereof connected with a power supply V_{DD} and aother terminal thereof connected with the switched current sources 353 and 354 respectively. The first control switch 351 is controlled by a control signal S_1, and the second control switch 352 is controlled by a control signal S_2. Furthermore, the input type switch 3533 controls the switched current source 353, and there is a current mirror composed of transistors 3531 and 3532. The first input of the switch 3533 is connected with the control signal S_2 and the second input is connected with the control signal S_1. The input type switch 3534 controls the switched current source 354, and there is a current mirror composed of transistors 3541 and 3542. The first input of the switch 3533 is connected with the control signal S1 and the second input is connected with the control signal S2.

The operations of the comparison unit 34 and current output unit 35 are described below. When the voltage V_{na} of the first connected output terminal O_a is higher than the voltage V_{nb} of the second connected output terminal Ob, the current flows out from the first connected output terminal O_a, resulting in that the voltage V_{na} rises, and the current flows in from the second connected output terminal O_b, resulting in that the voltage V_{nb} falls. Meanwhile the voltage of S_1 is high and that of S_2 is low, so that the first control switch 351 of the current output unit 35 is conductive and the switched current source 353 is also conductive. The current passes the first control switch 351 and flows out from the first drive terminal V_{o1} to drive the speaker 36 and flows in from the second drive terminal V_{o2} and then grounded through the switched current source 353. When the voltage V_{na} of the first connected output terminal O_a is lower than the voltage V_{nb} of the second connected output terminal O_b, the current flows out from the second connected output terminal O_b, resulting in that the voltage V_{nb} rises, and then the current flows in from the first connected output terminal O_a, resulting in that the voltage V_{na} falls. Meanwhile the voltage of S_1 is low and that of S_2 is high, so that the second control switch 352 of the current output unit 35 is conductive and the switched current source 354 is also conductive. The current passes the second control switch 352 and flows out from the second drive terminal V_{o2} to drive the speaker 36, and flows in from the first drive terminal V_{o1} and then grounded through the switched current source 354.

While the present invention has been described in conjunction with preferred embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. For example, in the embodiment the positions of the switch 351 and current source 353 can be exchanged. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and scope thereof as set forth in the appended claims.